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DESIGN VARIATIONS AND PERFORMANCE
CHARACTERISTICS OF THE OPEN-SLEEVE
DIPOLE

Jimmy L. Wong, et al

Aerospace Corporation

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Air Force Systems Command

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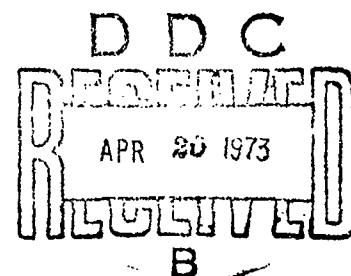
Design Variations and Performance Characteristics of the Open-Sleeve Dipole

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Prepared by J. L. WONG and H. E. KING
Electronics Research Laboratory
Laboratory Operations

73 JAN 15

Systems Engineering Operations
THE AEROSPACE CORPORATION



Prepared for SPACE AND MISSILE SYSTEMS ORGANIZATION
AIR FORCE SYSTEMS COMMAND
LOS ANGELES AIR FORCE STATION
Los Angeles, California

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FOREWORD

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This report, which documents research carried out from March through September 1972, was submitted on 2 February 1973 to Colonel William C. Schwitzgebel, SK, for review and approval.

Approved



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Publication of this report does not constitute Air Force approval of the report's findings or conclusions. It is published only for the exchange and stimulation of ideas.



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Asst. Deputy for Space
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<p>A detailed study has been made of the broadband characteristics of a balun-fed, open-sleeve dipole mounted in front of a metallic reflector. VSWR and pattern measurements were performed in the UHF band for a variety of dipole-sleeve arrangements. Multiple cylindrical-rod sleeves and flat sleeves of disc and Greek-cross shapes were experimentally evaluated. Gain data were obtained on a crossed dipole with a tick-tack-toe sleeve configuration. It is shown that, with a proper choice of sleeve parameters, the dipole can be operated over a bandwidth of over an octave with a voltage standing wave ratio (VSWR) of less than 2:1.</p>		

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I. INTRODUCTION

The basic characteristics of a balun-fed, open-sleeve dipole mounted in front of a metallic reflector have been described previously (Ref. 1). A crossed dipole with a single Greek-cross shaped sleeve has been used as the basic element in two array configurations (Refs. 2, 3). One of the interesting features of this antenna is that by simple addition of parasitic elements (sleeves) to a conventional cylindrical dipole, the VSWR bandwidth can be broadened significantly with negligible change in the radiation patterns. A comparison of the VSWR response of an open-sleeve dipole with that of a conventional cylindrical dipole of the same dimension is given in Fig. 1. It is seen that an open-sleeve dipole can be operated over a bandwidth of 1.8:1 as

compared with an operating bandwidth of 1.25:1 for a conventional cylindrical dipole.

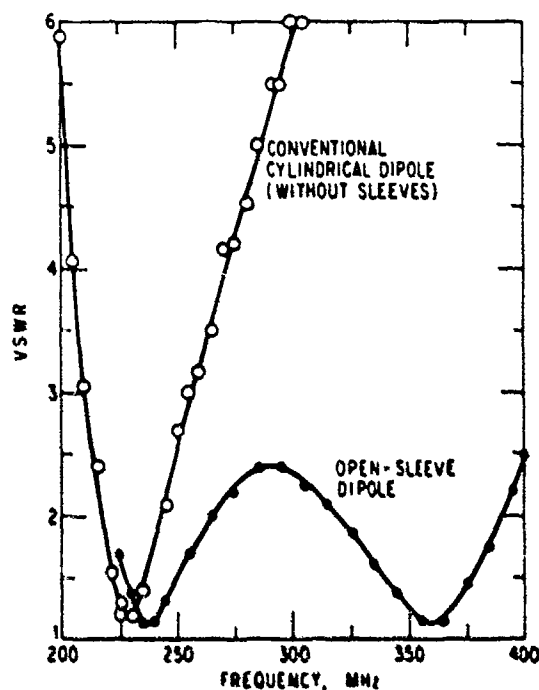


Fig. 1. VSWR response of open-sleeve dipole and conventional dipole.

This report provides a more detailed study of the open-sleeve dipole. Additional VSWR and pattern measurements are described for a variety of dipole-sleeve arrangements. Multiple cylindrical-rod sleeves and flat sleeves of disc and Greek-cross shapes were experimentally evaluated. It is shown that a multiple-sleeve arrangement can provide considerable improvement in VSWR response over that of a single-sleeve case. Gain measurements were made on a crossed dipole with a tick-tack-toe sleeve configuration.

II. DESCRIPTION OF OPEN-SLEEVE DIPOLES

In the initial study, cylindrical rods were used for the construction of the dipole and sleeves. The length of the sleeves were approximately one-half that of the dipole. Experimental studies indicated that a wide variety of sleeve configurations (shapes) can be used with no significant change in VSWR and pattern characteristics. For simplicity of construction, multiple flat-sleeve arrangements were selected for the major portion of this study. In addition, multiple cylindrical rod-sleeve dipoles were evaluated.

The construction details for the crossed flat-sleeve dipoles and balun are given in Figs. 2 to 4. Most of the measurements were made in the UHF frequency band. The dipole length was selected to have the antenna's lowest resonant frequency at approximately 500 MHz. Double and triple sleeve arrangements of a Greek-cross and a disc configuration are shown. Figure 5 depicts the multiple cylindrical-rod sleeve dipole.

The feed line for the dipole is a copper-clad 0.141-in.-diam semirigid coaxial cable. The balanced line of the balun is a length of 0.141-in.-diam rod. The short circuit of this line is coincident with the reflector surface. The dipoles are screwed into the feed terminals, and the sleeves are supported by teflon or styrofoam spacers (not shown in sketches).

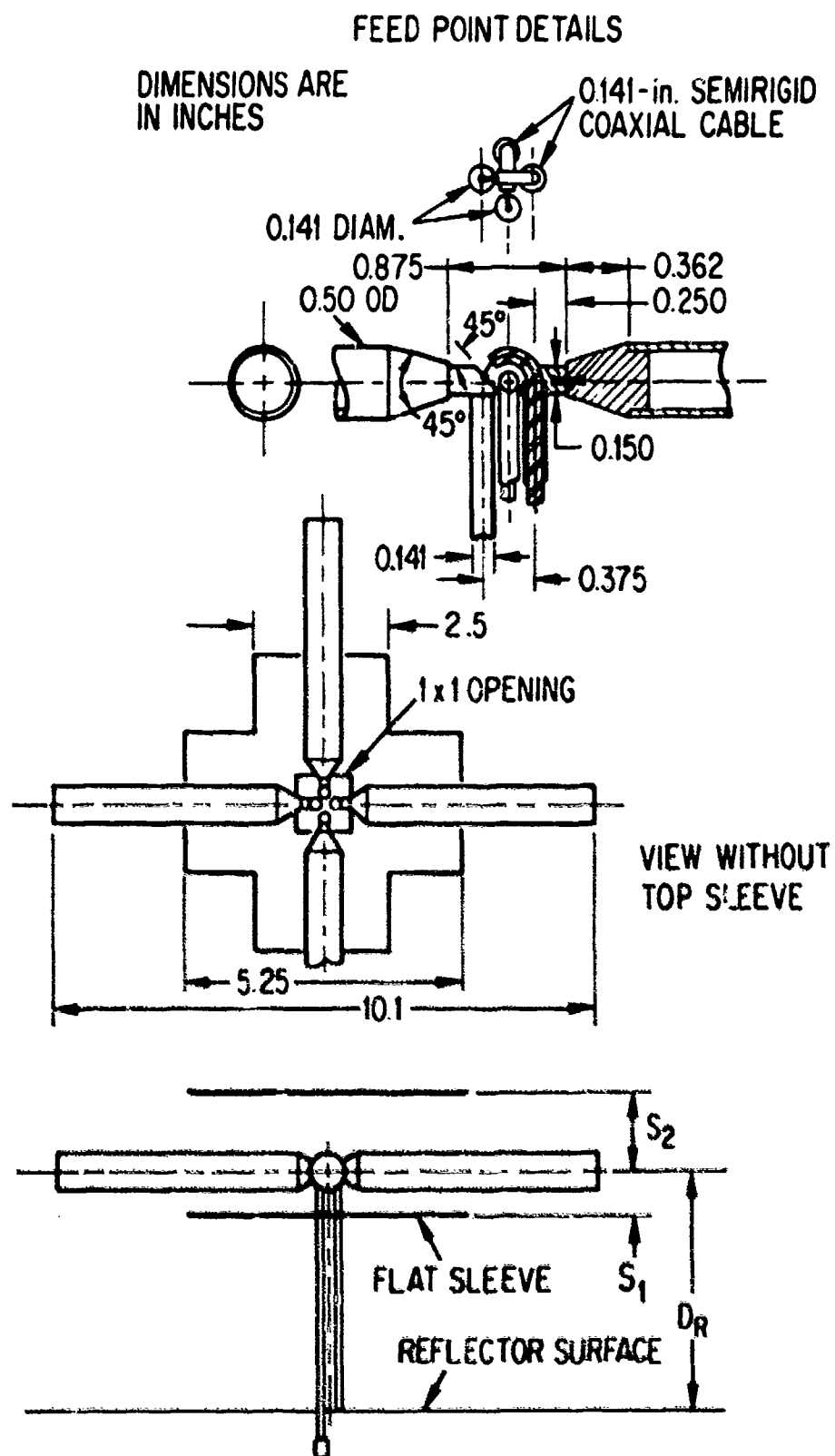


Fig. 2. Dual flat-sleeve dipole model

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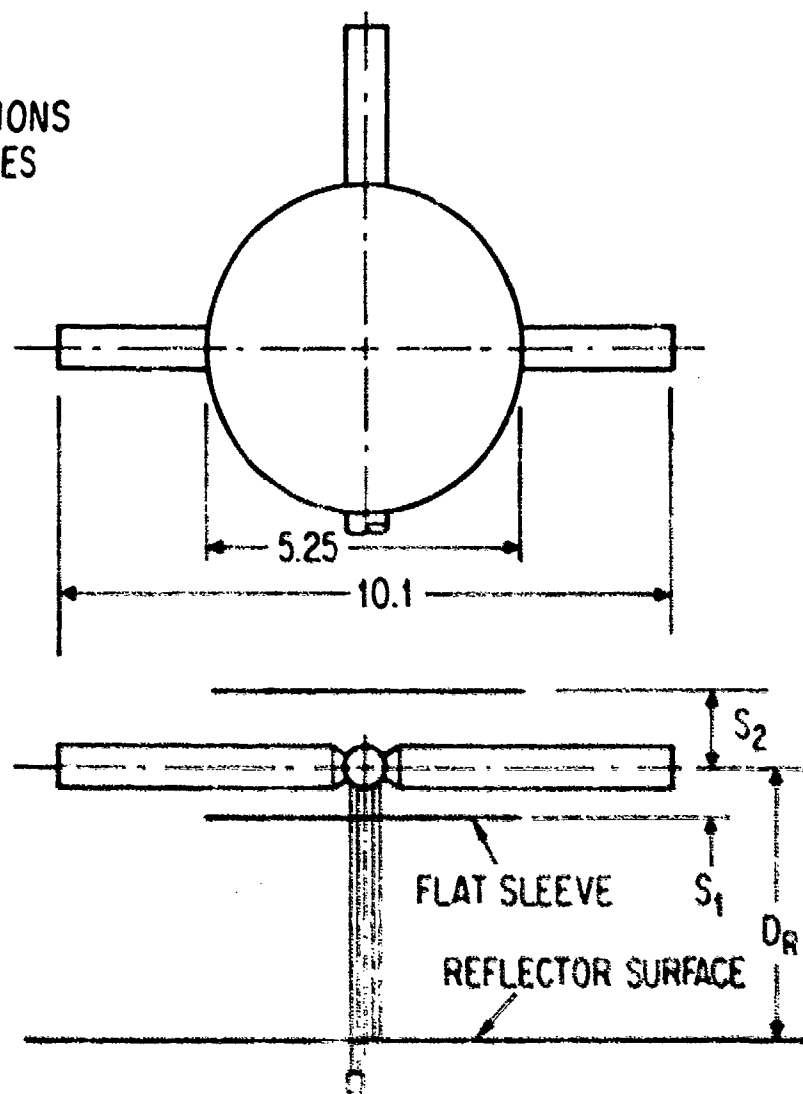


Fig. 3. Dual flat-disk-sleeve dipole model

DIMENSIONS
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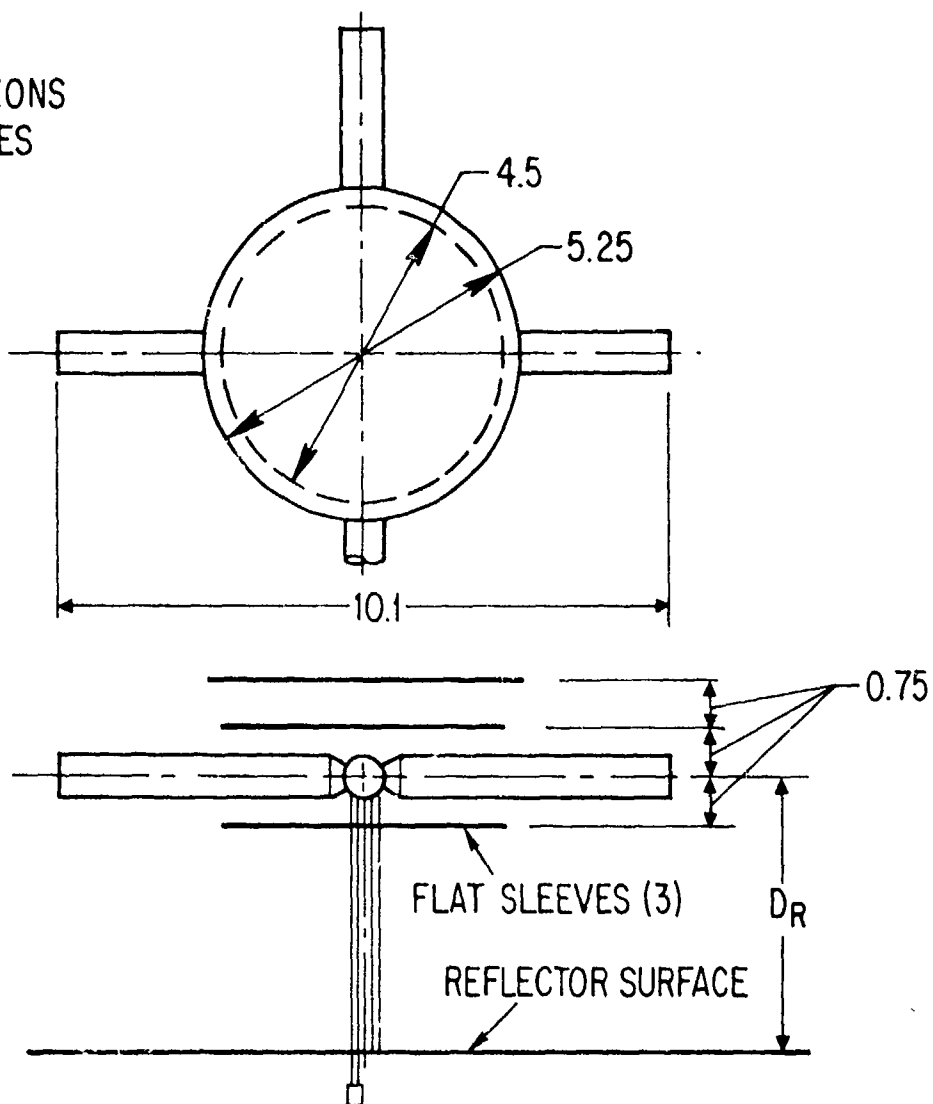


Fig. 4. Triple flat-disc-sleeve dipole model

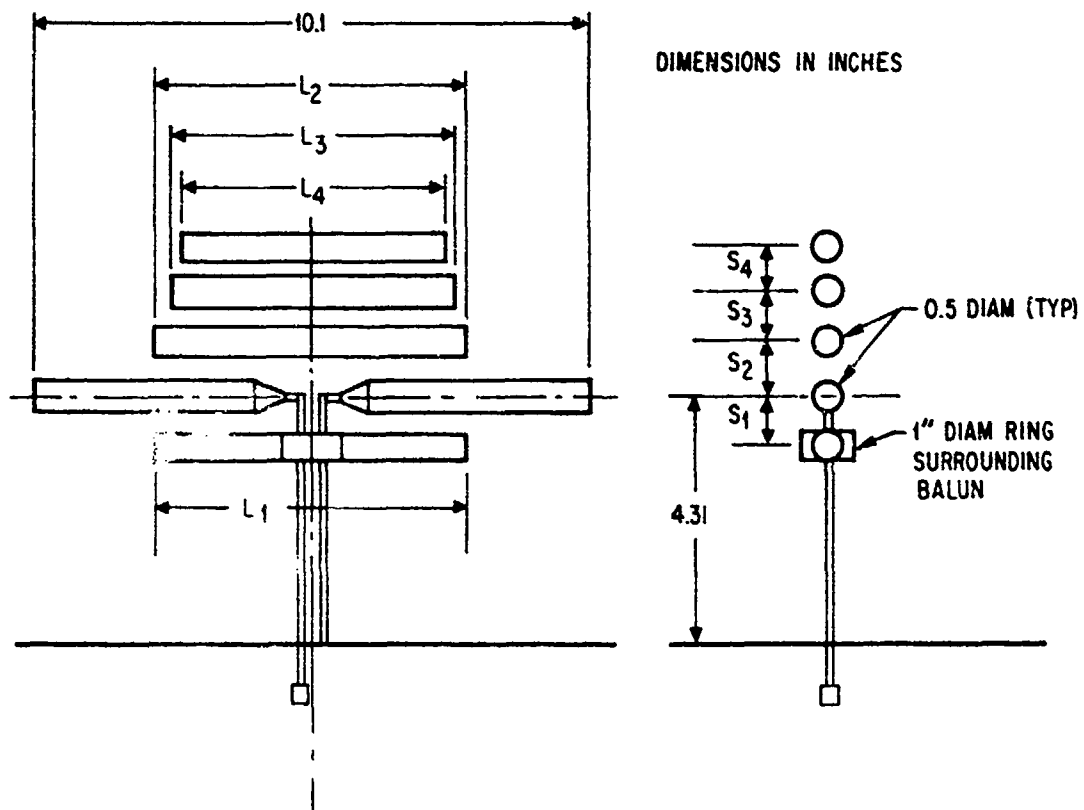
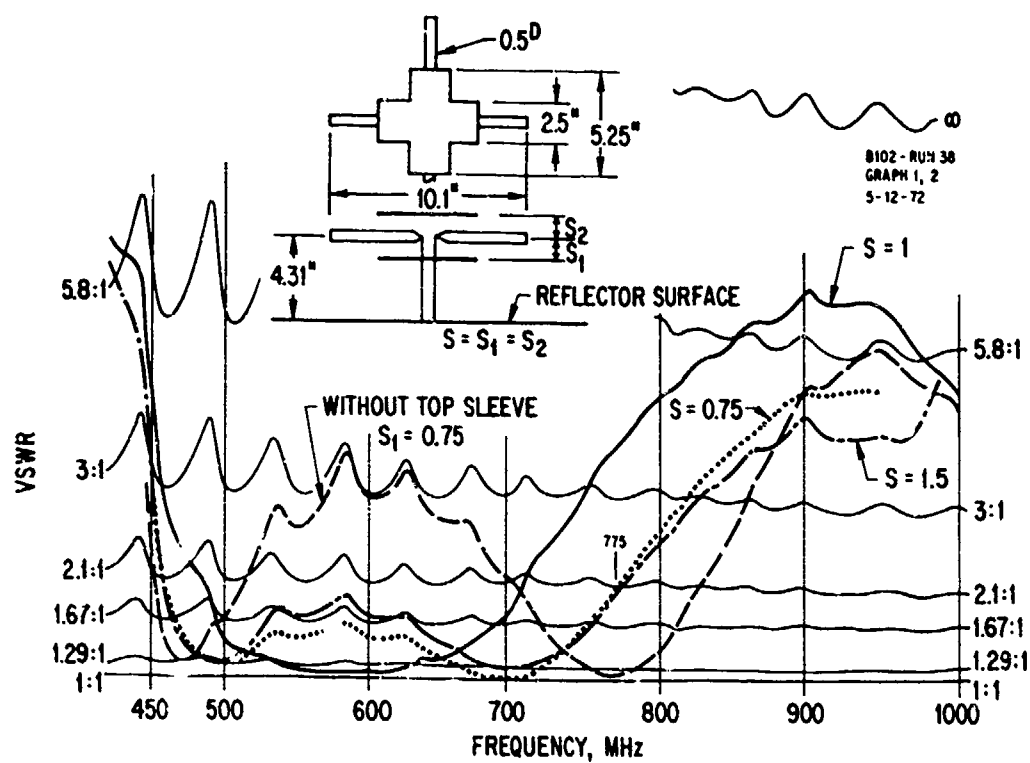


Fig. 5. Multiple cylindrical-rod-sleeve dipole model

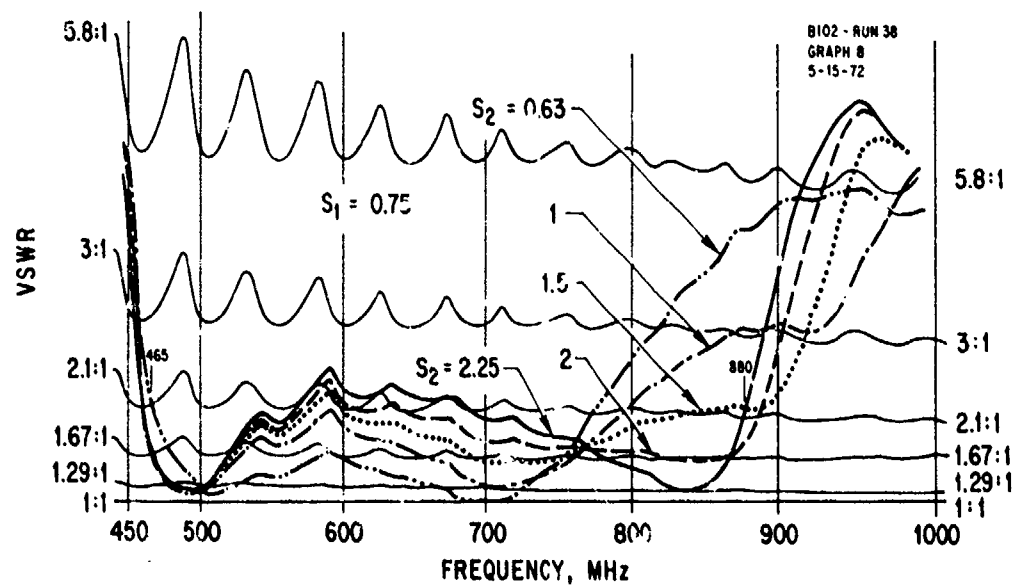
III. VSWR

Swept-frequency VSWR measurements were made with the dipole mounted in front of a 52-in. square reflector. The measurements were made on one dipole with the orthogonal dipole terminated in a 50- Ω load. Figure 6(a) shows the VSWR response of a dipole with dual Greek-cross shaped sleeves located at the same distance from the dipole. The VSWR response for a dipole with only a single sleeve (top sleeve removed) is also shown for comparison. It is seen that addition of the second sleeve changes the VSWR response considerably. The overall bandwidth is reduced, but the midband performance is significantly improved with a VSWR of less than 1.29:1 over a 100-MHz band. For wideband operations, the spacing between the top sleeve and the dipole can be increased. For example, the maximum VSWR can be kept under 2.2:1 over a 1.9:1 frequency ratio when S_1 and S_2 are equal to 0.75 and 2.25 in., respectively [see Fig. 6(b)]. Figure 7 shows the VSWR characteristics as a function of dipole-to-reflector spacing. As expected, the midband VSWR performance is improved as the dipole-to-reflector spacing is increased with some narrowing of the overall bandwidth (less than 5%). For systems applications, the choice of a proper dipole-to-reflector spacing also depends on pattern and gain requirements.

In the sweep-frequency VSWR curves of Figs. 6 and 7 and all subsequent figures with various sleeve configurations, the VSWR response at the low end remains essentially unchanged. Thus, it may be concluded that the low-end response is controlled primarily by the dipole length and not the sleeve parameters. All the VSWR curves demonstrate how the overall bandwidth and midband peak VSWR can be controlled by the sleeve dimensions, sleeve-to-dipole spacing, number of sleeves, and dipole-to-reflector spacing. It should be pointed out that the dipole diameter has been fixed in these experiments and that the diameter can also be changed if further optimization is desired (Ref. 1).

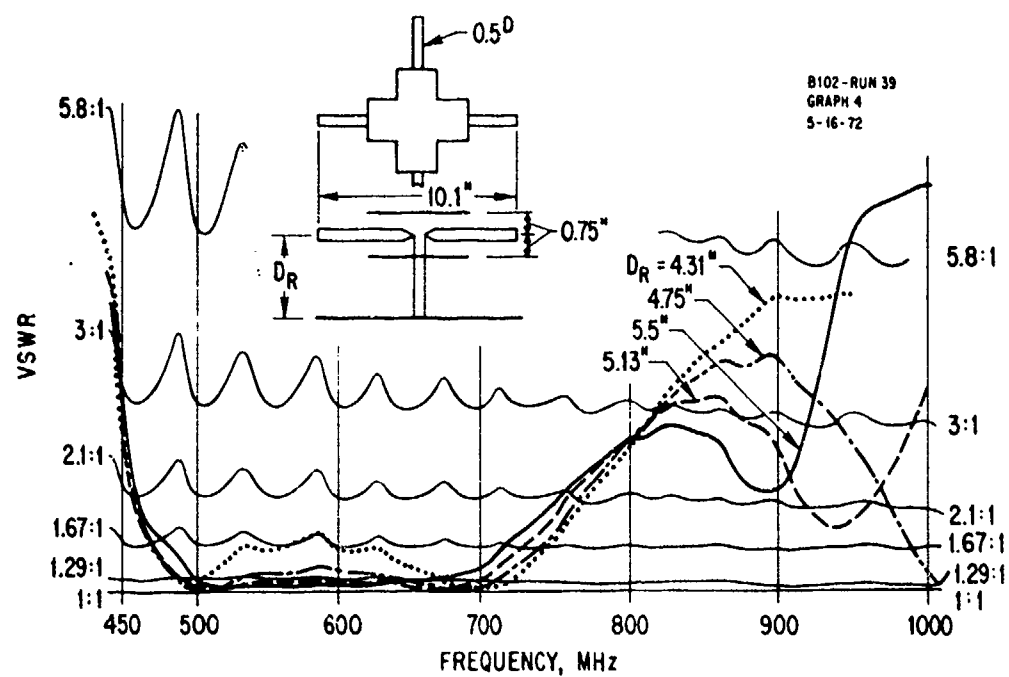


(a) EQUAL SLEEVE-TO-DIPOLE SPACING

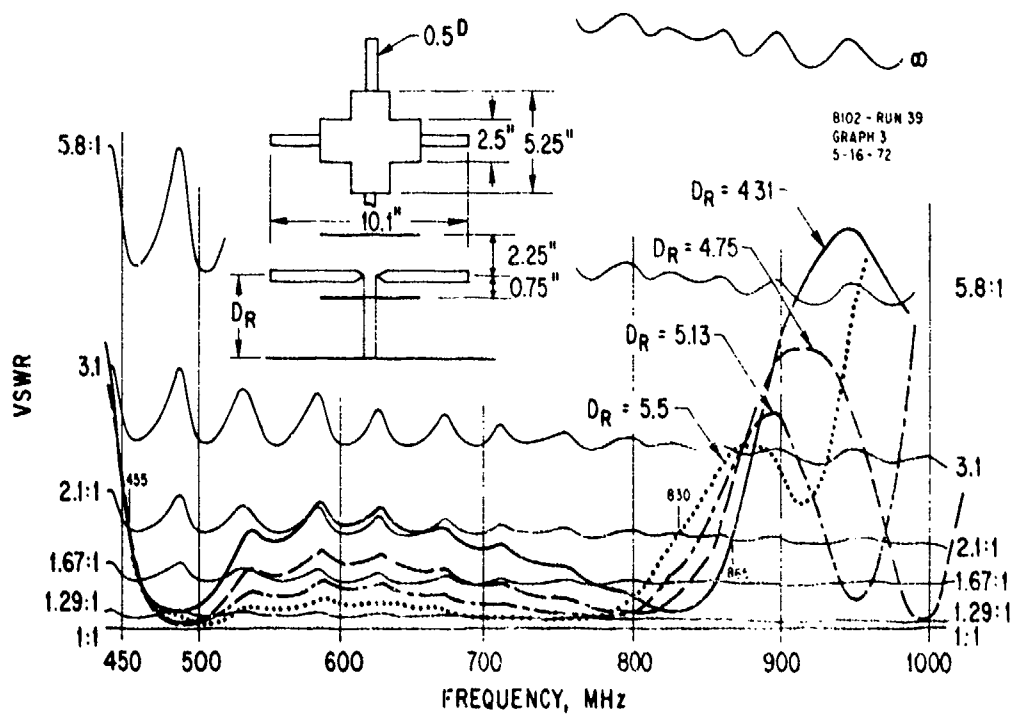


(b) UNEQUAL SLEEVE-TO-DIPOLE SPACING

Fig. 6. VSWR response of dipole with dual Greek-cross shaped sleeves



(a) EQUAL SLEEVE-TO-DIPOLE SPACING



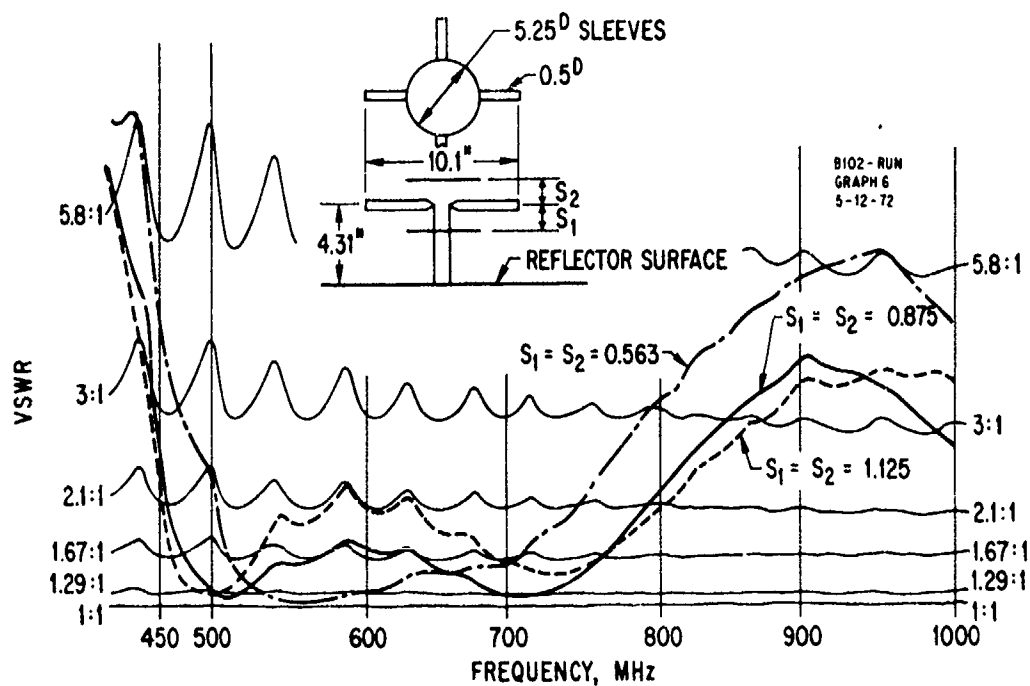
(b) UNEQUAL SLEEVE-TO-DIPOLE SPACING

Fig. 7. VSWR response of dual Greek-cross sleeve dipole with various dipole-to-reflector spacings

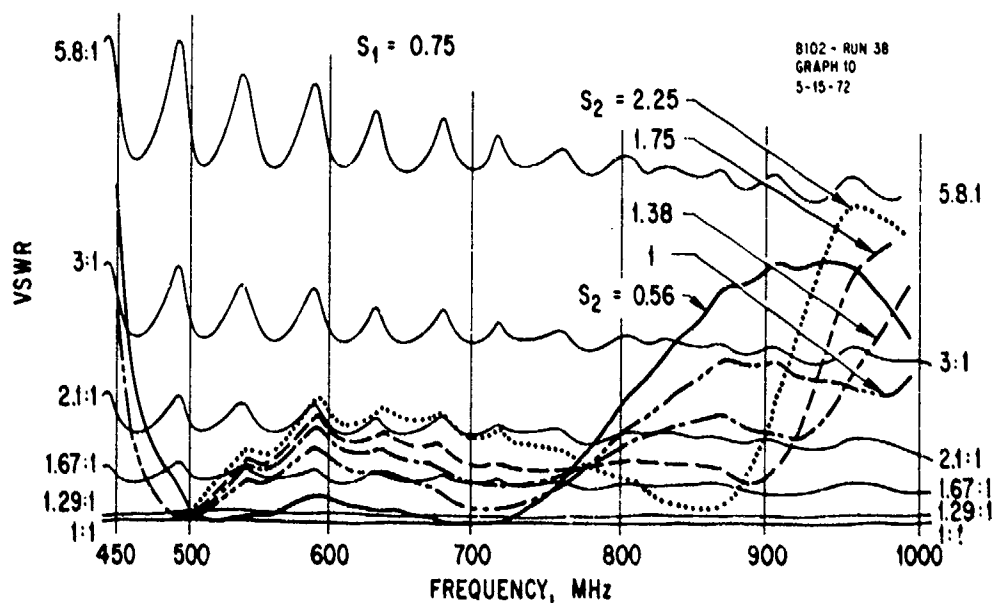
A dipole with dual disc sleeves (Fig. 3) also resulted in a favorable VSWR response as illustrated in Fig. 8. Figure 8(a) shows the VSWR when both sleeves are spaced equidistant from the dipole; Fig. 8(b) shows the VSWR when the bottom sleeve is held at a fixed distance of 0.75-in. from the dipole, while the sleeve-to-dipole spacing for the top sleeve is varied. The 5.25-in.-diam sleeve dimension was experimentally determined as it yielded good VSWR characteristics. The circular sleeve results are very similar to those of the Greek-cross sleeves. The VSWR characteristics for various dipole-to-reflector spacings were not measured, but it is anticipated that the results should be similar to the curves of Fig. 7. Combinations of the Greek-cross and the disc sleeves gave similar results to those found for the identical cross or circular sleeves.

A triple circular sleeve arrangement (Fig. 4) can provide a considerable improvement in VSWR performance over that of a single or double sleeve configuration. The addition of a third sleeve has resulted in a bandwidth of over an octave with a VSWR of less than 2:1 as shown in Fig. 9(a). The VSWR response as a function of dipole-to-reflector spacing is depicted in Fig. 9(b). It can be seen that the midband VSWR response is improved with a slight decrease in the overall bandwidth.

In the original measurements (Ref. 1), the open sleeves (cylindrical rods) and dipole were coplanar in the plane parallel to the reflector. As indicated in Ref. 1, the VSWR response is relatively insensitive to the location of the sleeves, provided that the sleeve-to-dipole spacing is maintained. Figure 10 shows an arrangement with the plane of the sleeves and dipole perpendicular to the reflector. Figure 10(a) shows the VSWR characteristics with the bottom sleeve-to-dipole spacing fixed at 0.75-in. and the top-sleeve spacing varied; Fig. 10(b) shows the VSWR curves with both cylindrical-rod sleeves equidistant from the dipole and the length of the top sleeve varied. The 5.69-in. sleeve length was previously selected as near optimum. Nevertheless, with variable sleeve spacings, length, and diameter, there are still more parameters that can be varied to achieve the best VSWR response for a particular use.

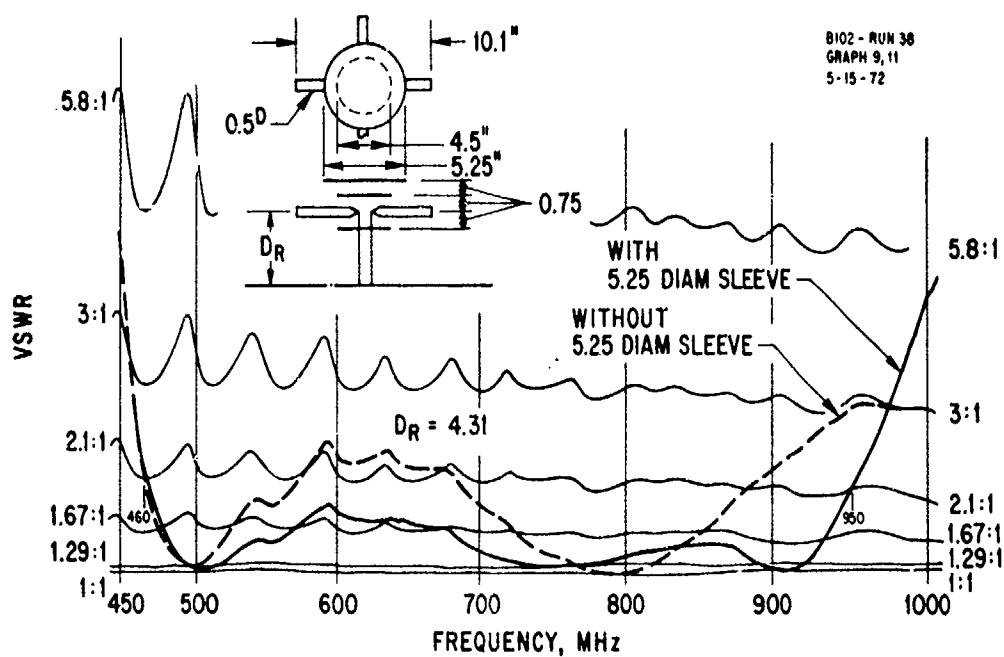


(a) EQUAL SLEEVE-TO-DIPOLE SPACING

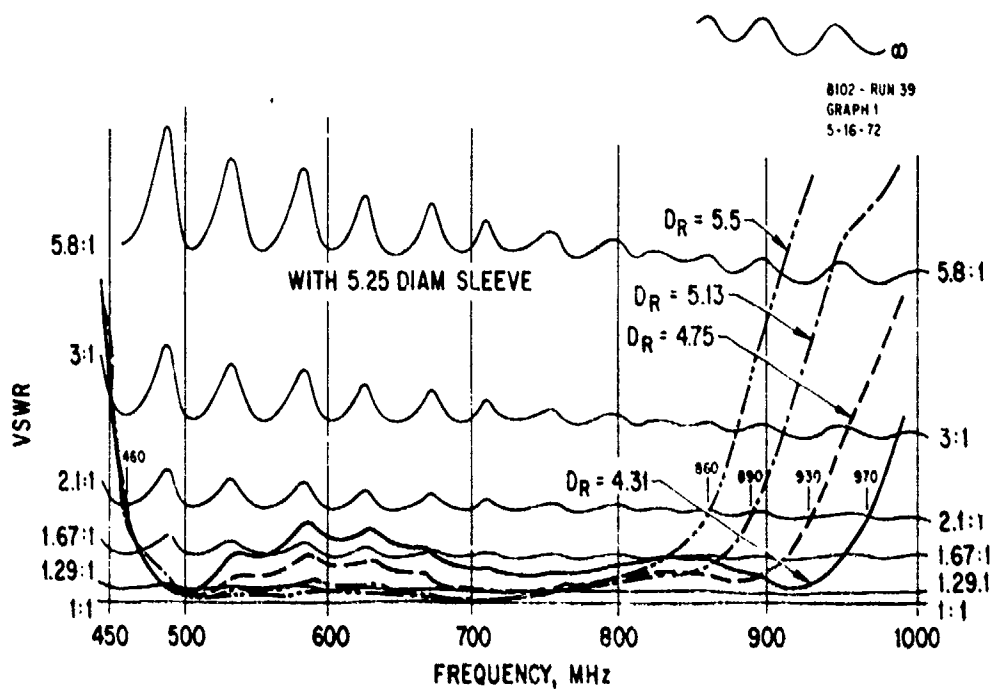


(b) UNEQUAL SLEEVE-TO-DIPOLE SPACING

Fig. 8. VSWR response of dual-disc-sleeve dipole

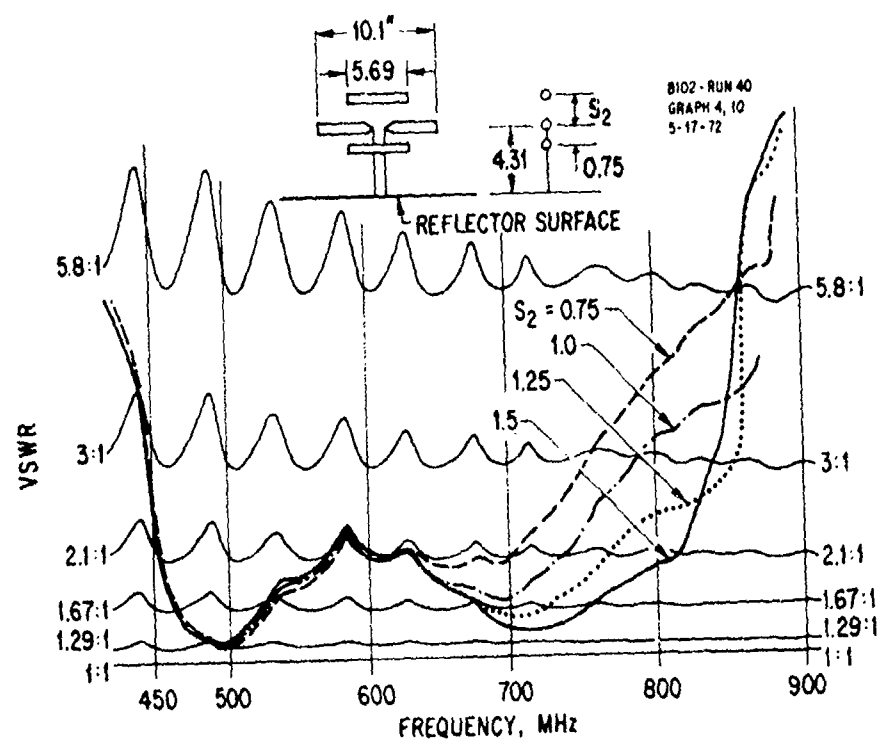


(a) COMPARISON OF DUAL AND TRIPLE DISC SLEEVE DIPOLE

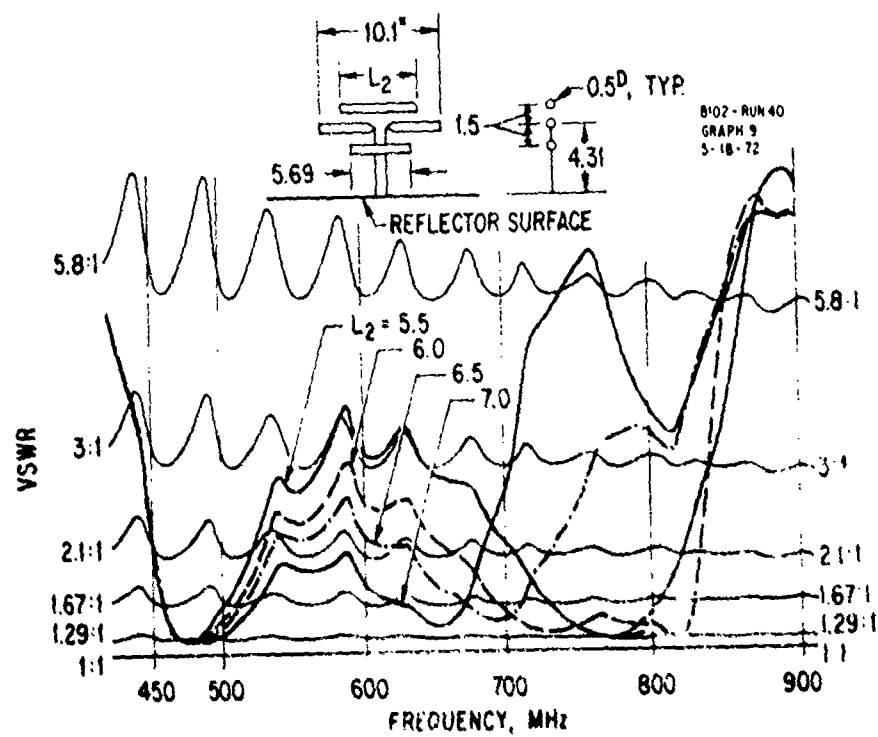


(b) VARIABLE DIPOLE-TO-REFLECTOR SPACINGS

Fig. 9. VSWR response of dual-disc-sleeve dipole



(a) UNEQUAL OPEN-SLEEVE SPACING



(b) EQUAL OPEN-SLEEVE SPACING WITH VARIABLE LENGTH OF TOP SLEEVE

Fig. 10. VSWR response of open-sleeve (two cylindrical rods) dipole

A multiple-sleeve arrangement that employs four cylindrical-rod sleeves (Fig. 5) was tested and found to provide improved VSWR performance over that of a dual rod-sleeve configuration. The measured VSWR characteristics as a function of dipole-to-reflector spacing are shown in Fig. 11. This configuration provides a multitude of parameters that can be varied to derive the optimum VSWR response.

Flat metal strips may be used for the construction of the dipole and sleeves. On the basis of the equivalent radius concept, the width of the strip is equal to twice the diameter of a cylindrical rod. Figure 12 shows the VSWR characteristics of an open-sleeve dipole with both the dipole and sleeves constructed of flat metal strips. The strips may be oriented either parallel with or perpendicular to the reflector. The VSWR response of a cylindrical-rod configuration is also shown for comparison, and only a small difference is observed. A flat-strip construction may be useful when a low cross-section configuration is desired.

Another variation of the open-sleeve dipole is the curved sleeve configuration as shown in Fig. 13. The sleeve is in the form of a circular arc spaced at a distance S from the dipole. Figure 13 shows the VSWR response for various sleeve-to-dipole spacings. The purpose of this experiment was to investigate the feasibility of this configuration, and no attempt was made to optimize the VSWR performance.

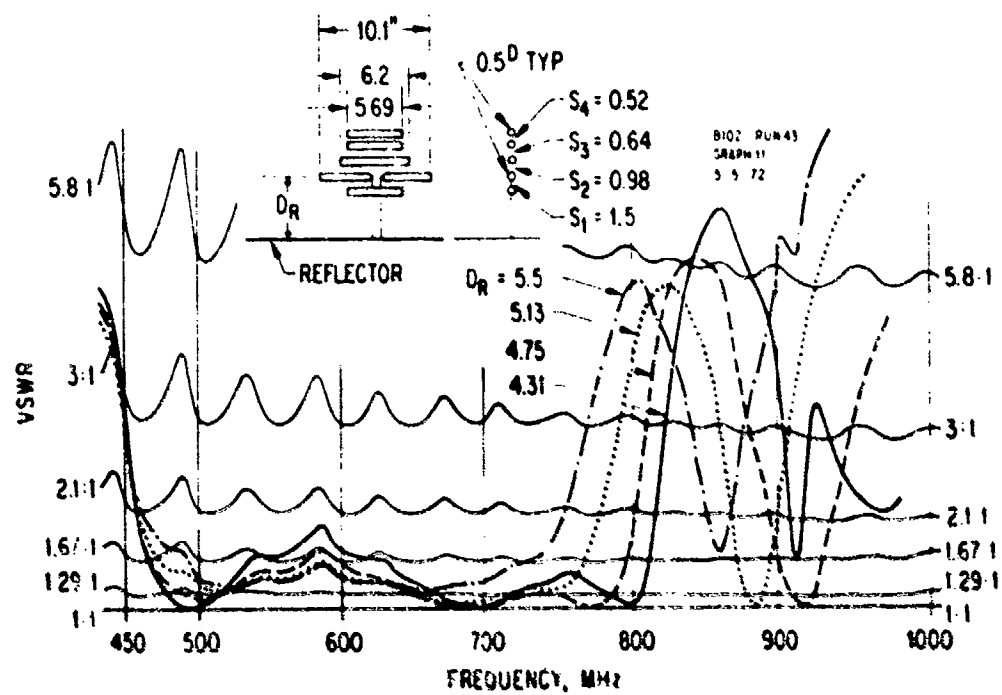
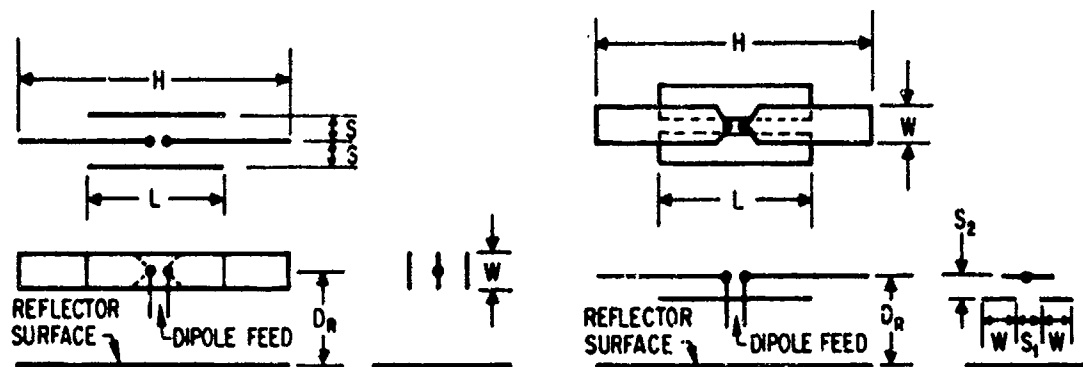


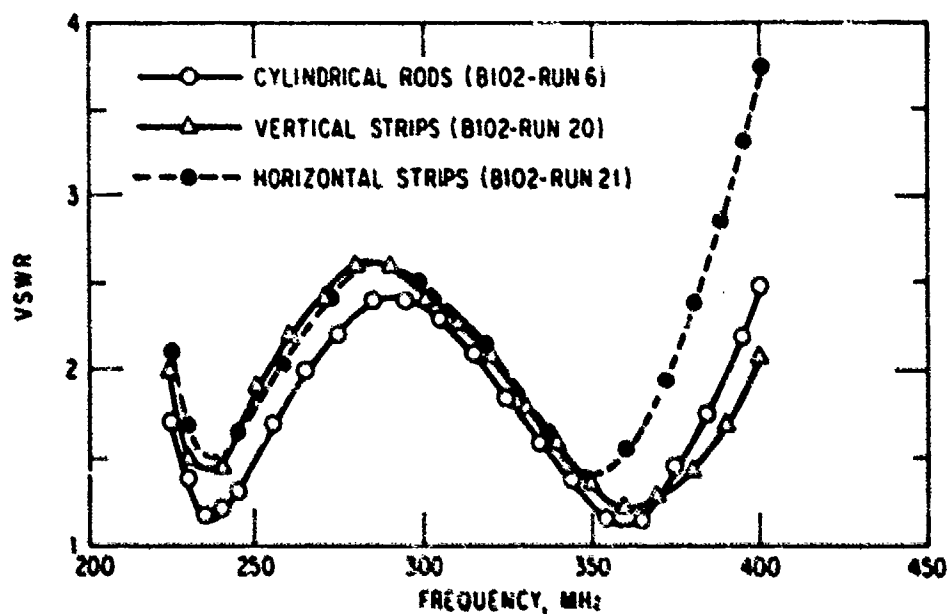
Fig. 11. VSWR characteristics of a multiple-rod open-sleeve dipole



(a) VERTICAL STRIP DIPOLE AND SLEEVES

(b) HORIZONTAL STRIP DIPOLE AND SLEEVES

	$\frac{H}{\text{INCHES}}$	$\frac{L}{\text{INCHES}}$	$\frac{D}{\text{INCHES}}$	$\frac{W}{\text{INCHES}}$	$\frac{S}{\text{INCHES}}$	$\frac{S_1}{\text{INCHES}}$	$\frac{S_2}{\text{INCHES}}$	$\frac{D_R}{\text{INCHES}}$
	20.2	11.38	1.13	—	2.0	—	—	8.62
	19.38	11.0	—	2.25	1.0	—	—	8.62
	19.38	11.0	—	2.25	—	2.25	0.5	8.62



(c) VSWR RESPONSE

Fig. 12. VSWR characteristics of flat-strip open-sleeve dipole

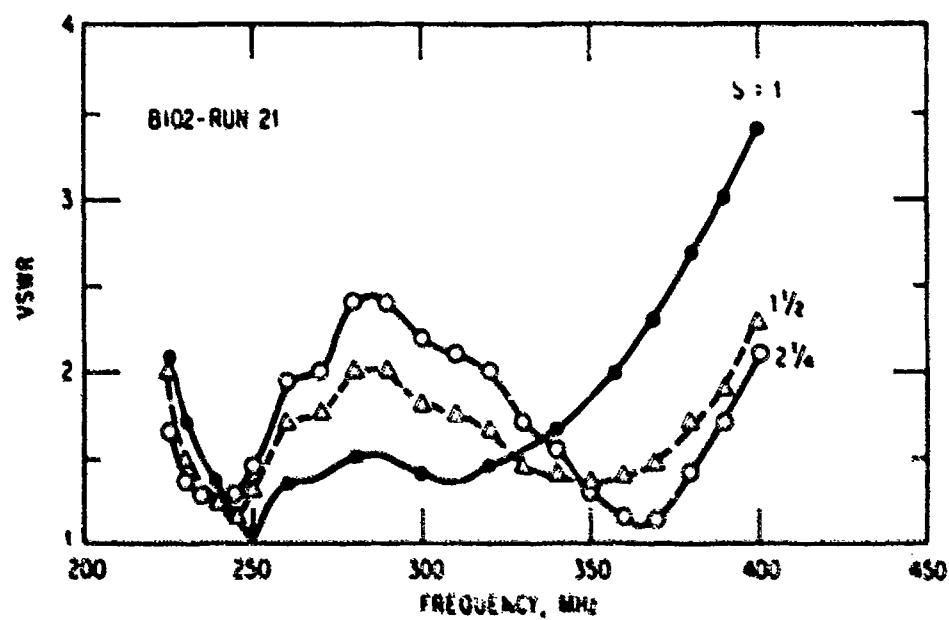
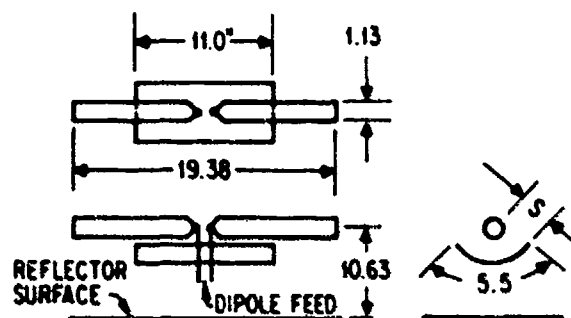







Fig. 13. VSWR (curved sleeve)

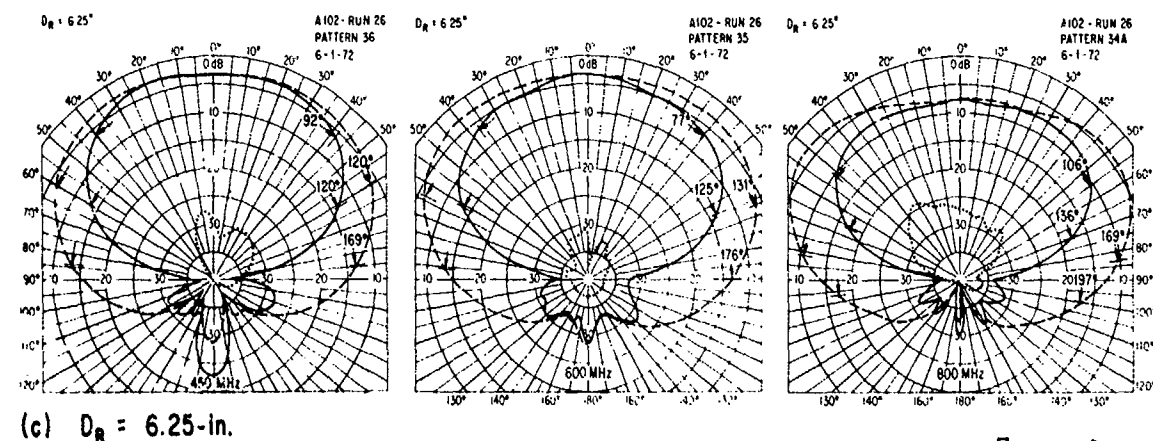
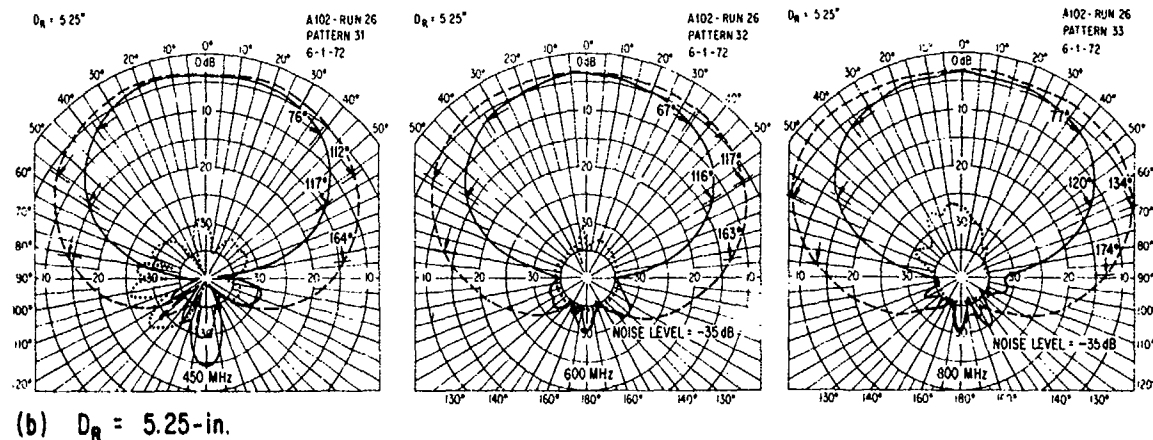
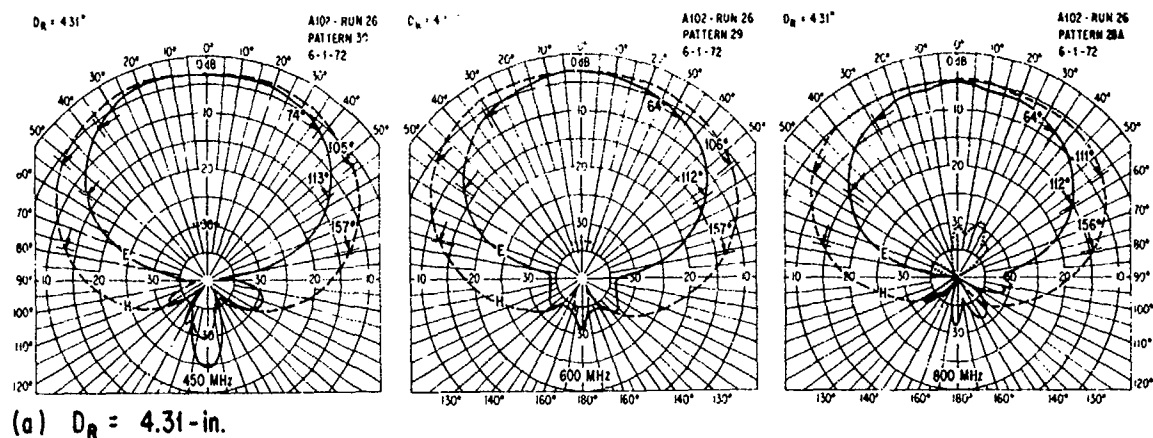
IV. PATTERNS

Radiation patterns of various sleeve-dipole configurations were measured at 450, 600, and 800 MHz and for dipole-to-reflector spacings of 4.31, 5.25, and 6.25 in. Linear polarization was used in these measurements. Patterns were measured for the sleeve-dipole arrangements that yielded good VSWR characteristics over the band. The patterns are shown in Figs. 14 to 19, and the corresponding sleeve configurations are shown in Table 1. The -3 and -10 dB beamwidths with respect to the on-axis field strength are indicated on each of the patterns.

Cross polarization is generally less than -20 dB, and it is attributed primarily to the coupling to the orthogonal dipole. Removal of the orthogonal dipole reduced the cross-polarization level to below -25 dB on axis.

Table 1. Sleeve Configurations for Measured Patterns

FIGURE	SLEEVE CONFIGURATION
14	SINGLE BOTTOM CROSS  SLEEVE
15	DUAL  SLEEVE, $S_1 : S_2 : 0.75$
16	DUAL  SLEEVE, $S_1 : 0.75, S_2 : 2.25$
17	DUAL DISC  SLEEVE, $S_1 : S_2 : 0.88$
18	TRIPLE  SLEEVE
19	MULTIPLE CYLINDRICAL-ROD SLEEVES



— E PLANE
 --- H PLANE
 CROSS POLARIZATION

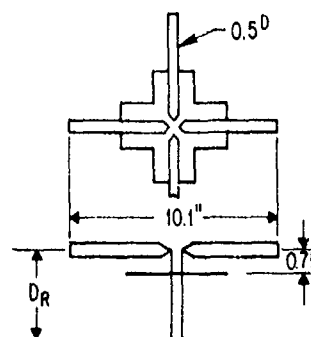
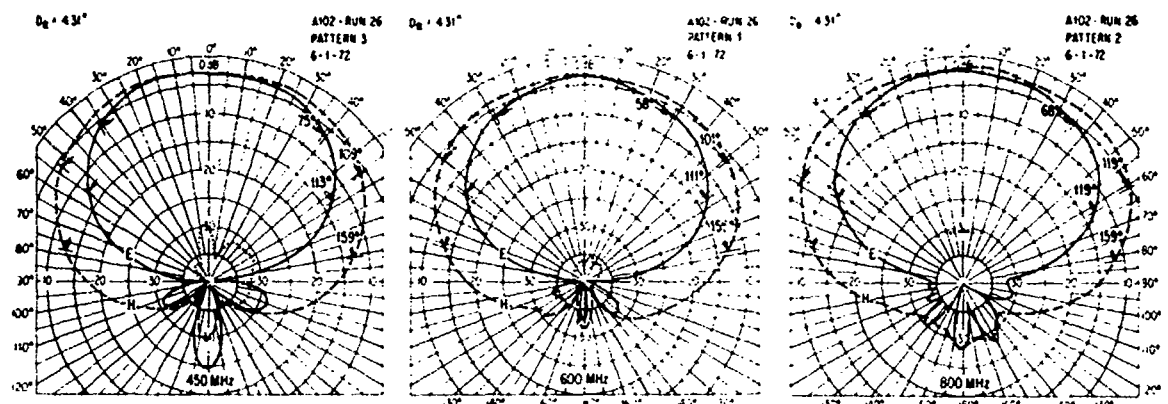
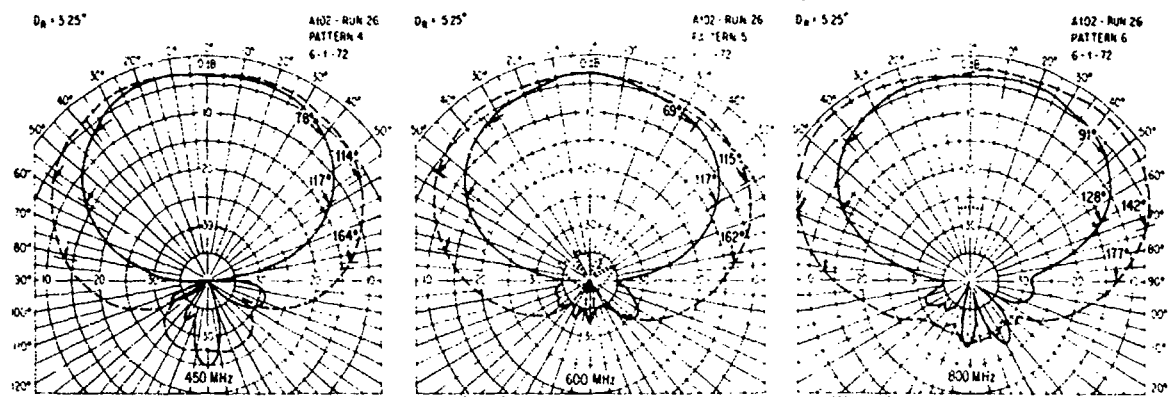


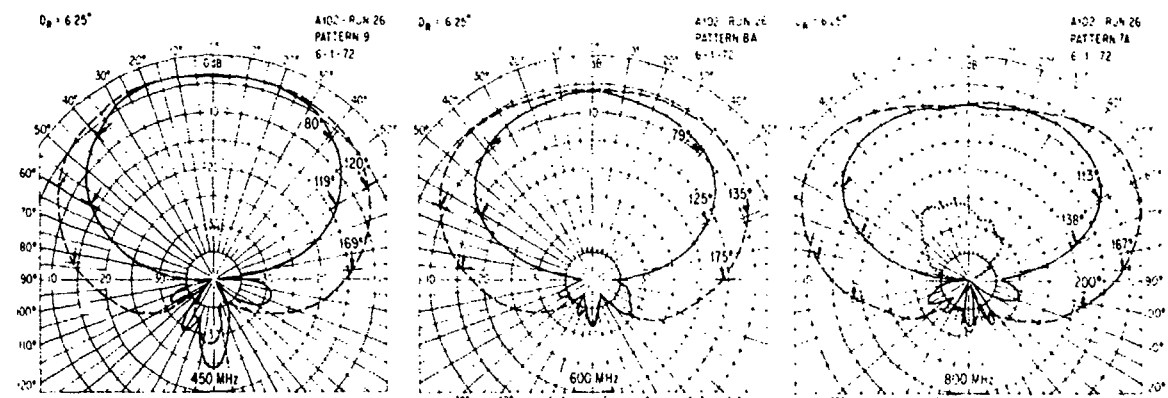
Fig. 14. E- and H-plane radiation patterns of single-cross-sleeve dipole



(a) $D_R = 4.31$ -in.



(b) $D_R = 5.25$ -in.



(c) $D_R = 6.25$ -in.

— E PLANE
 - - - H PLANE
 CROSS POLARIZATION

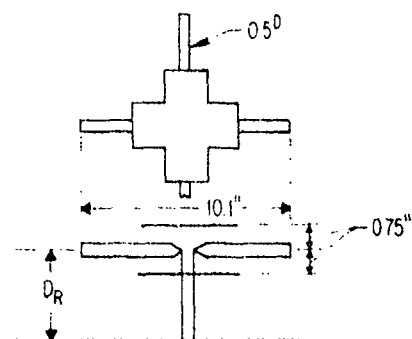
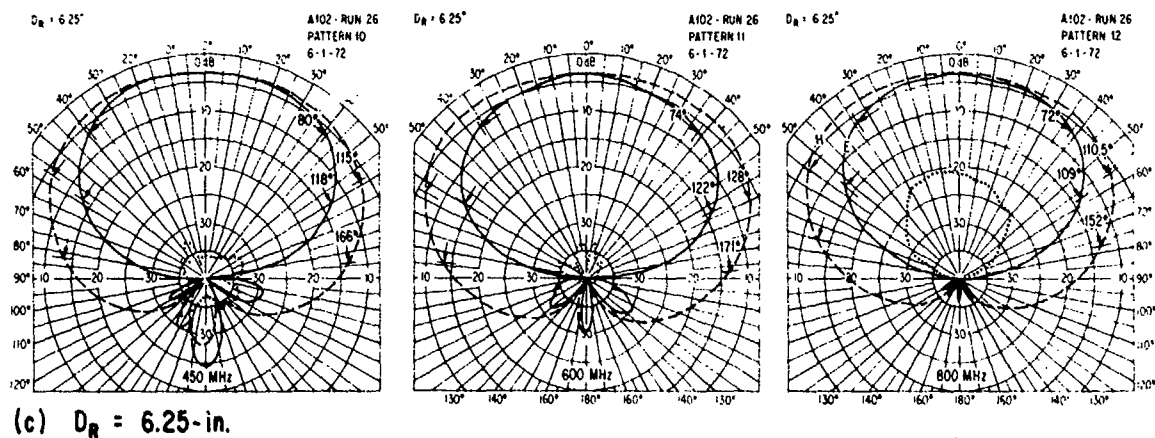
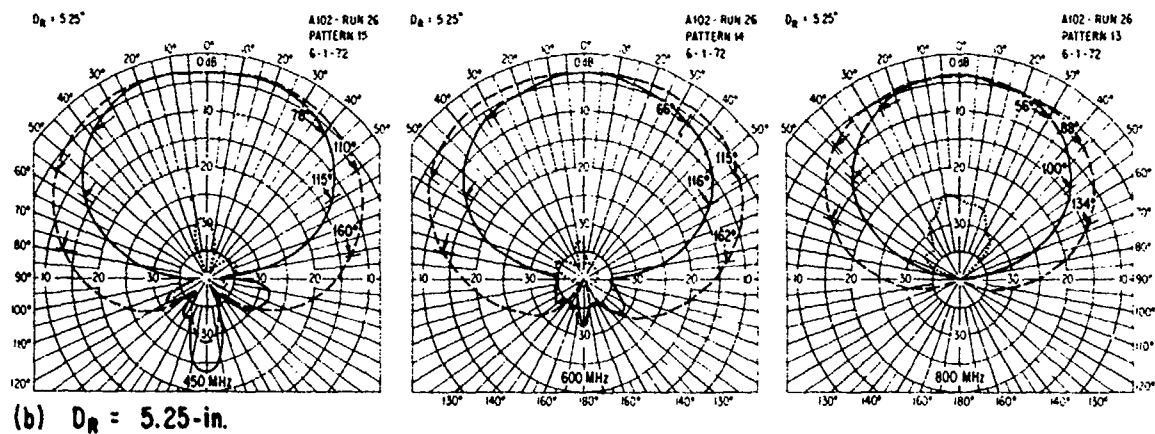
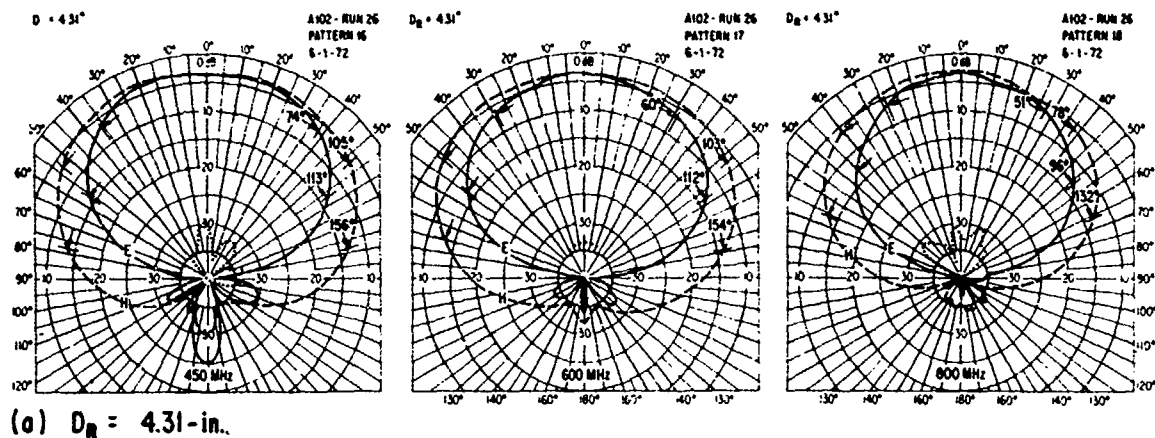
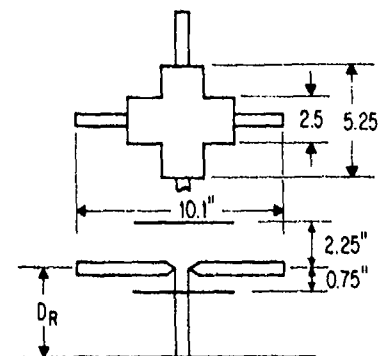


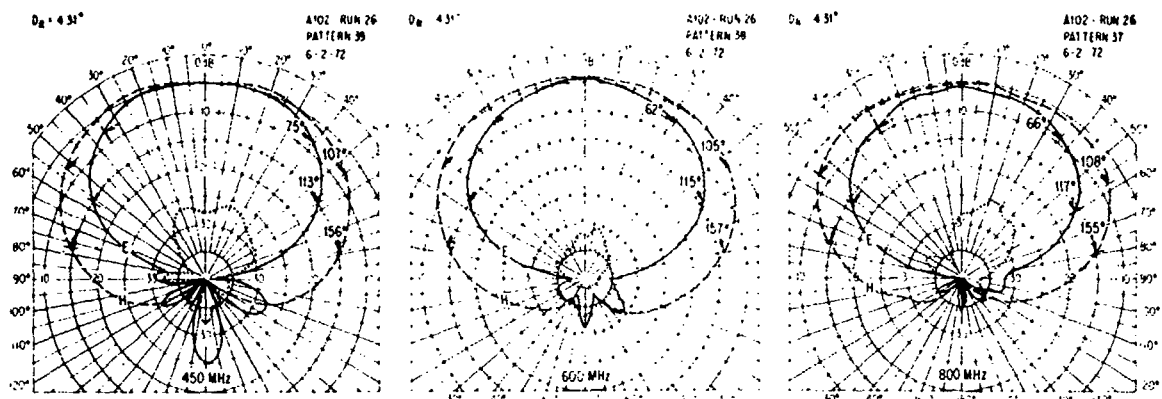
Fig. 15. E- and H-plane radiation patterns of dual-cross-sleeve dipole (equal sleeve spacing).



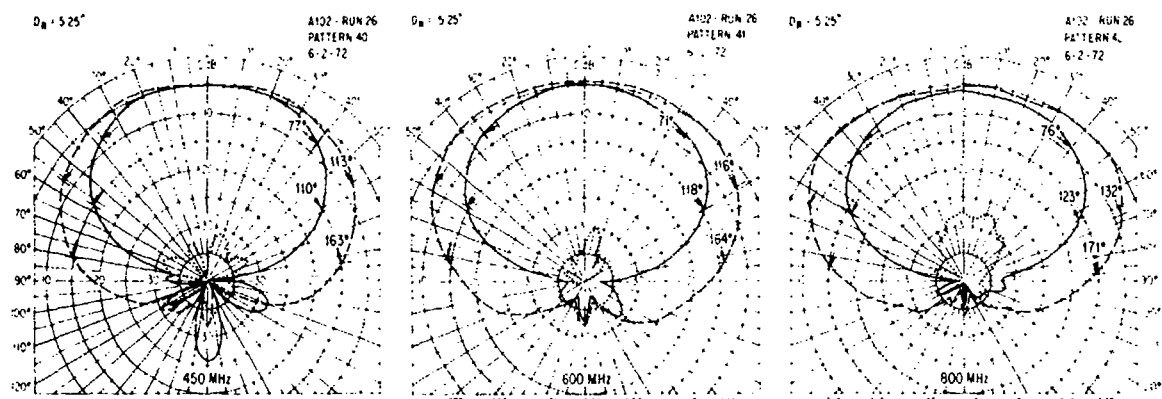
— E PLANE
- - - H PLANE
..... CROSS POLARIZATION

Fig. 16. E- and H-plane radiation patterns of dual-cross-sleeve dipole (unequal sleeve spacing)

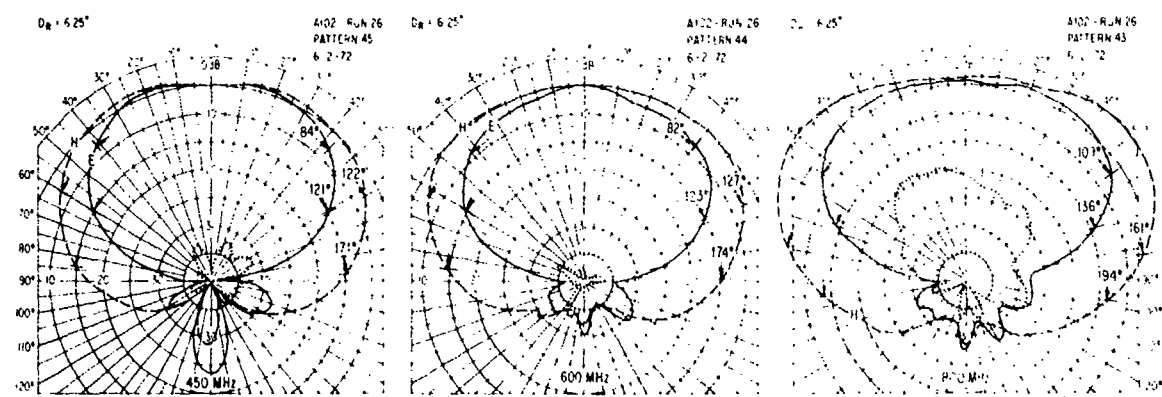




(a) $D_R = 4.31$ -in.



(b) $D_R = 5.25$ -in.



(c) $D_R = 6.25$ -in.

— E PLANE
 - - - H PLANE
 CROSS POLARIZATION

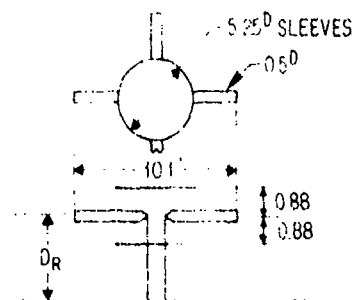
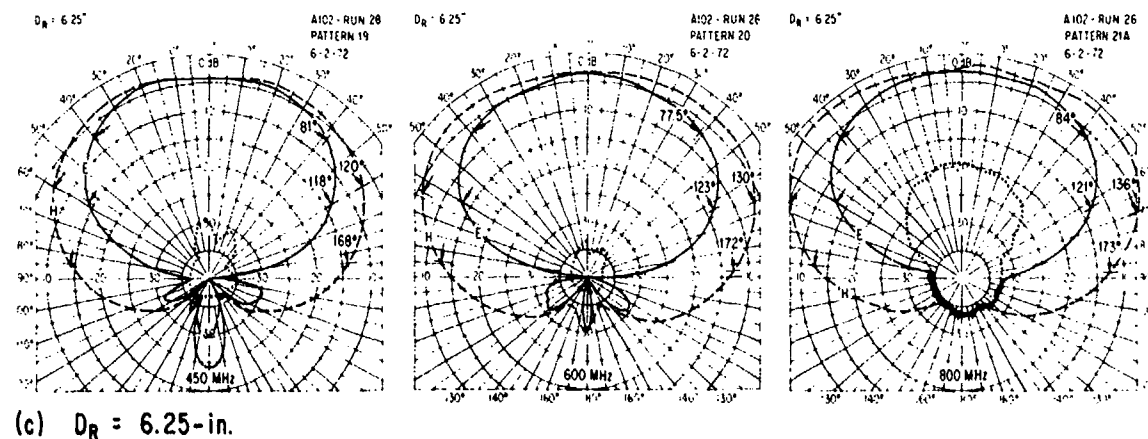
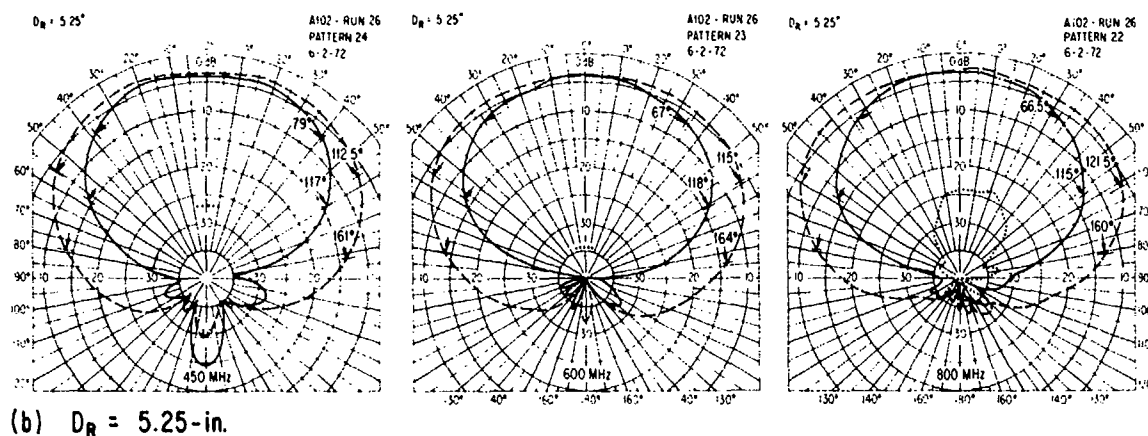
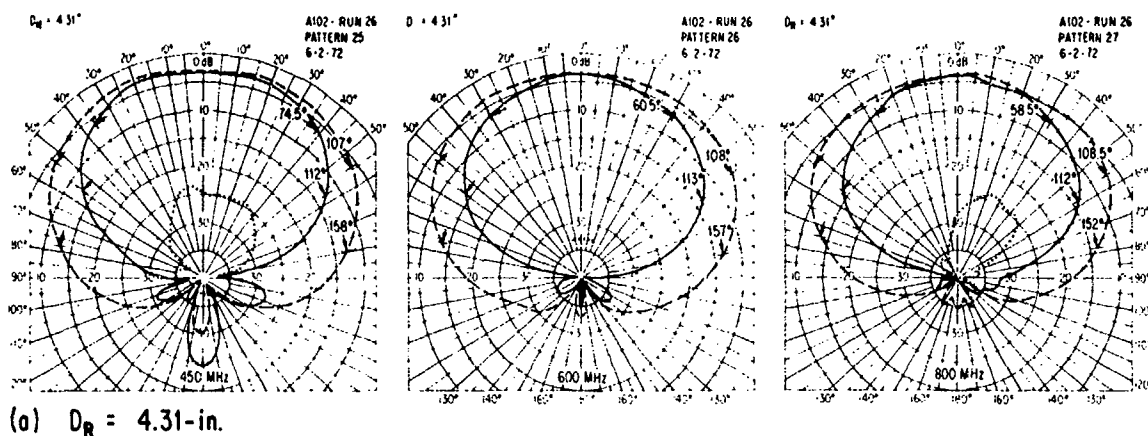


Fig. 17. E- and H-plane radiation patterns of dual-circular-sleeve dipole



— E PLANE
--- H PLANE
..... CROSS POLARIZATION

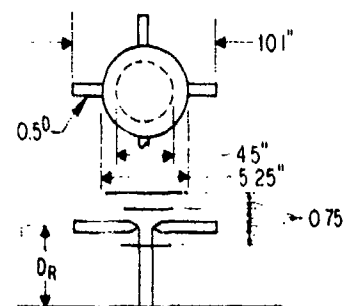
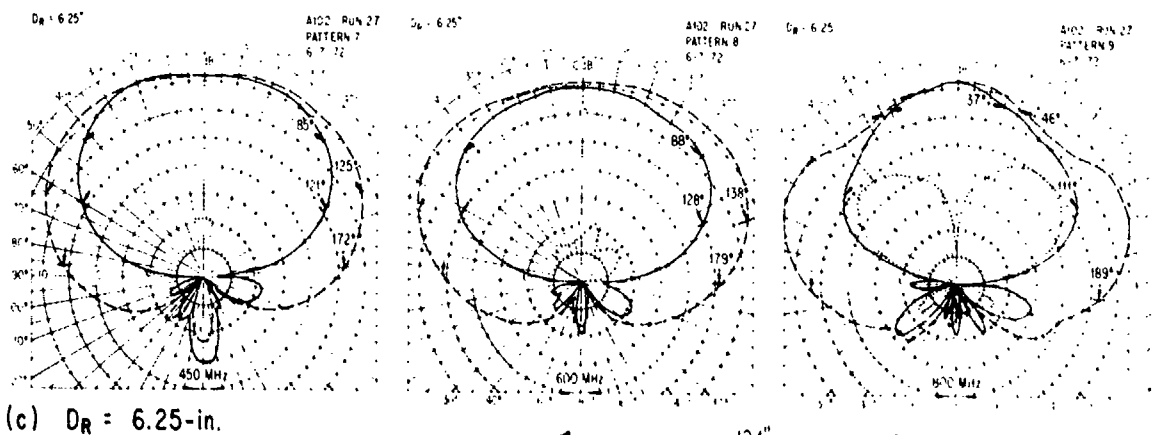
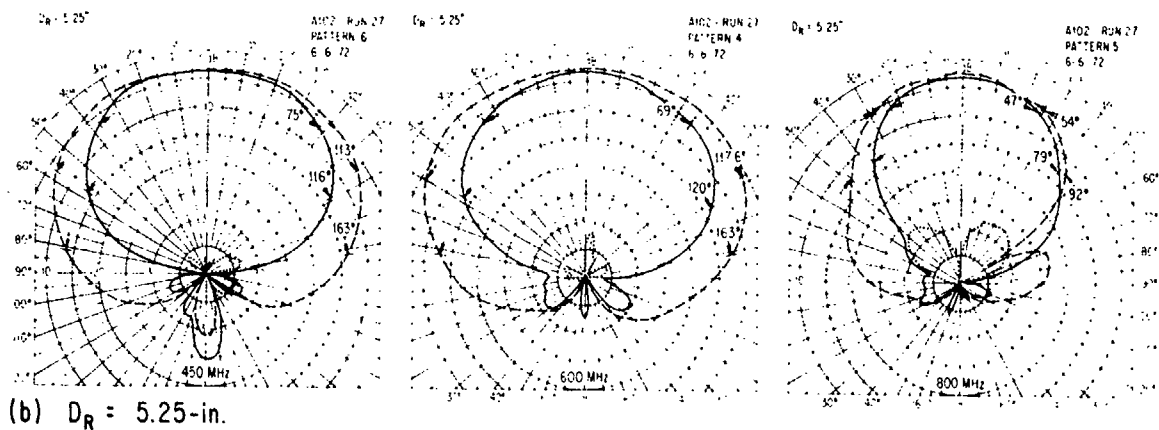
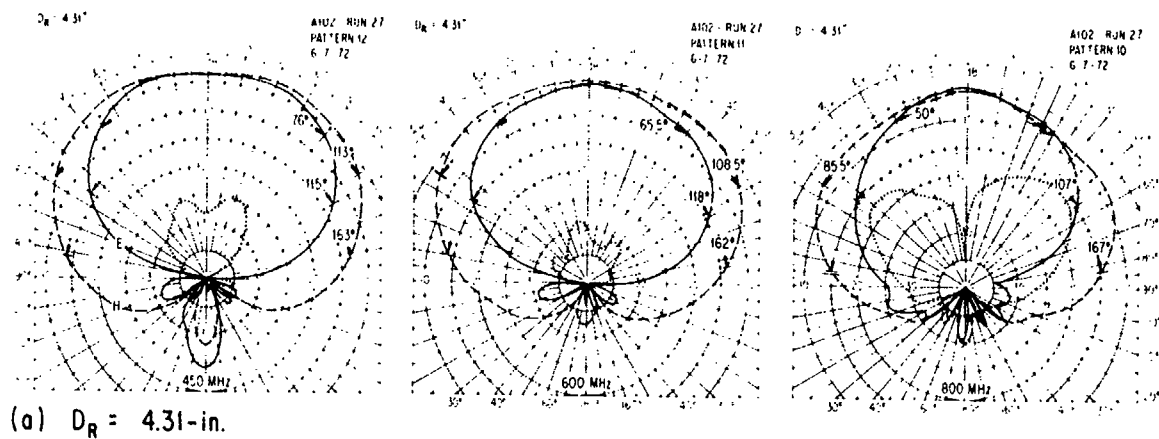


Fig. 18. E- and H-plane radiation patterns of triple-circular-sleeve dipole



— E PLANE
- - - H PLANE
..... CROSS POLARIZATION

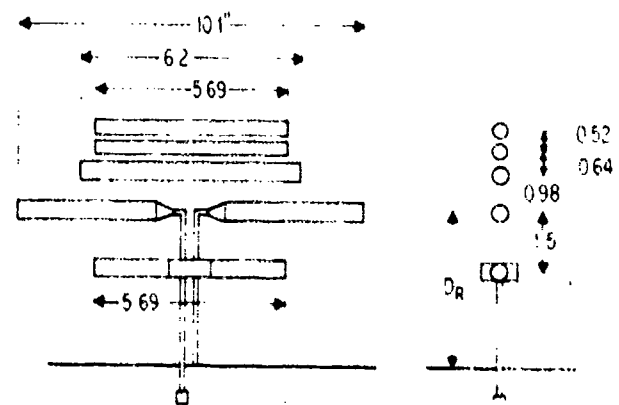


Fig. 19. E- and H-plane radiation patterns of four-element rod-sleeve dipole

A composite summary of the pattern characteristics of various sleeve-dipole configurations may be viewed from the product of the E- and H-plane half-power beamwidths as shown in Fig. 20. The beamwidth product for each configuration is compared to that of a dipole with a single Greek-cross sleeve. For the dual-sleeve configurations (both the Greek-cross and disc shapes) where the sleeve-to-dipole spacing is less than 0.88-in., the beam-width products are essentially the same as shown in Figs. 20(a) and 20(b). When the outboard sleeve is spaced farther from the dipole, some narrowing of the half-power beamwidth is noted at 800 MHz as indicated in Figs. 20(c) and 20(d). This beamwidth narrowing tends to suggest that some enhancement in directivity is possible. However, this is not necessarily true for all cases, since the measured patterns indicate that the pattern skirts are also widened, and a multilobe structure exists in some cases. The beamwidth product of the four-element rod-sleeve dipole is plotted in Fig. 20(e). This configuration resembles a Yagi antenna. Measurements showed that at 800 MHz considerable pattern sharpening occurred near the beam axis, indicating the possible coexistence of a traveling-wave mode.

The patterns of Figs. 14, 15, and 17 were compared with the computed patterns of a thin dipole in front of an infinite reflector. Generally, the measured patterns resemble the theoretical patterns for a fixed dipole-to-reflector spacing over the 450- to 800-MHz frequency band. Figure 21 depicts the measured patterns for a dual Greek-cross sleeve dipole as compared with the theoretical dipole-reflector patterns. Conventional array pattern computational techniques were used to determine the theoretical patterns with the dipole field represented by

$$E(\theta) = \frac{\cos[(\beta L/2) \sin \theta] - \cos(\beta L/2)}{\cos \theta}$$

where L is the total length of the dipole. The measured patterns for the single-sleeve and dual-disc sleeve dipoles are similar to those found in Fig. 21.

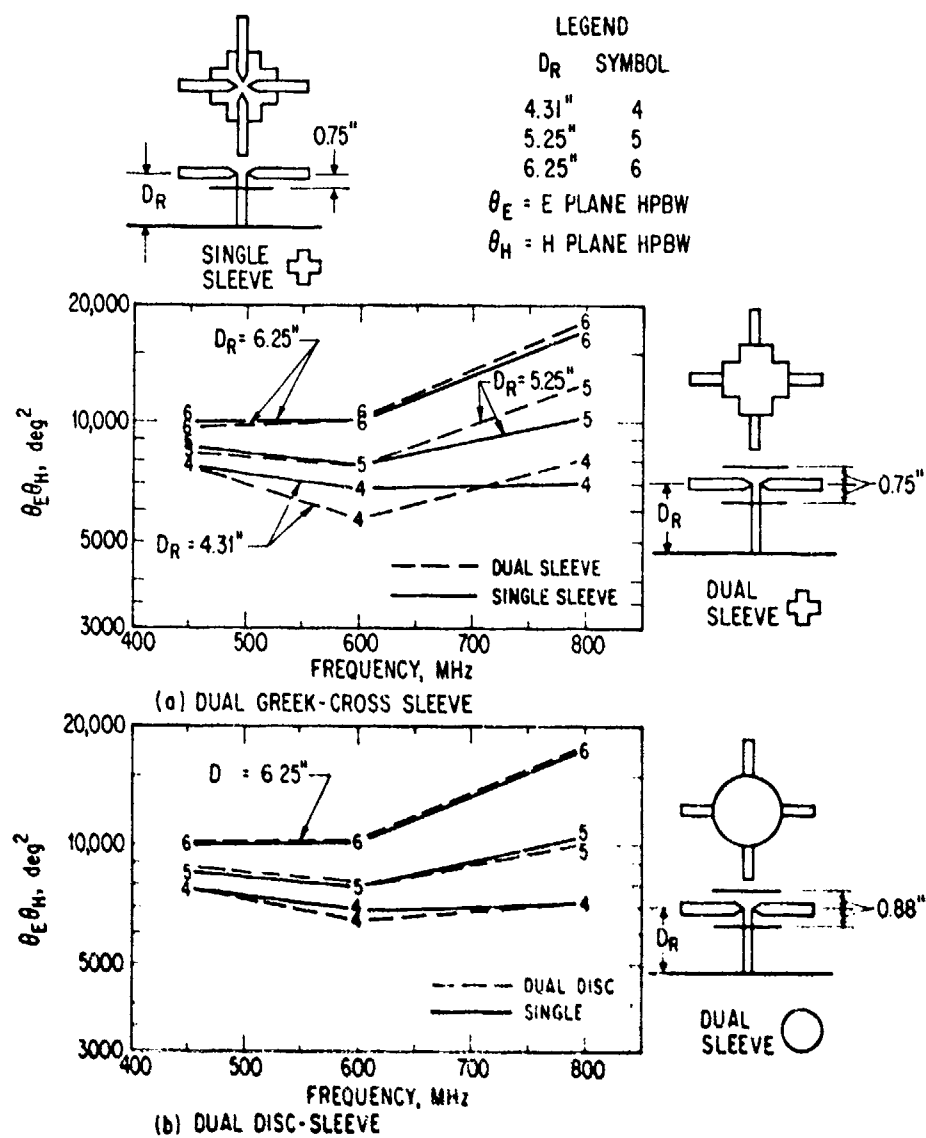


Fig. 20. Half-power beamwidth product for various sleeve dipole configurations

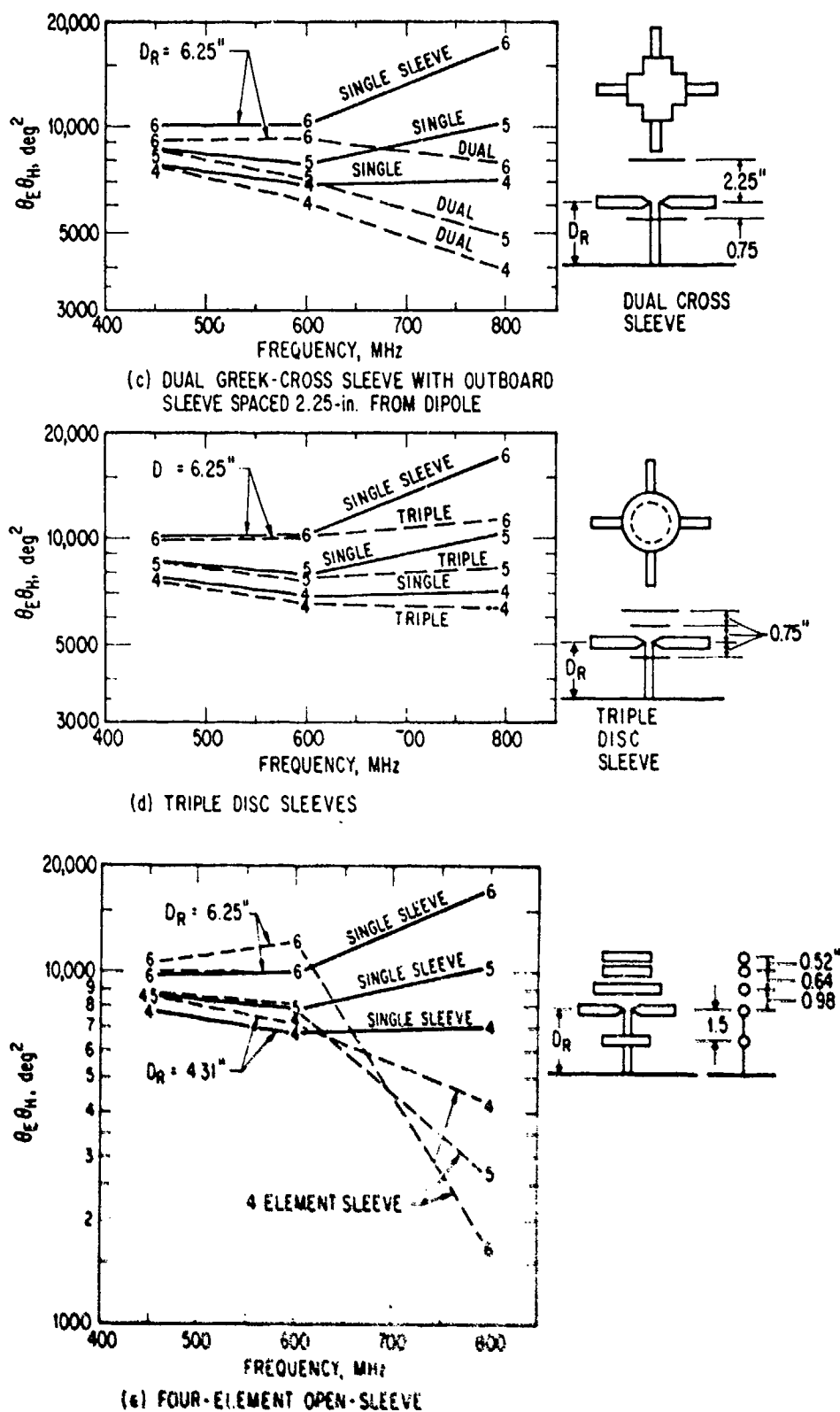


Fig. 20. Half-power beamwidth product for various sleeve dipole configurations (Concluded)

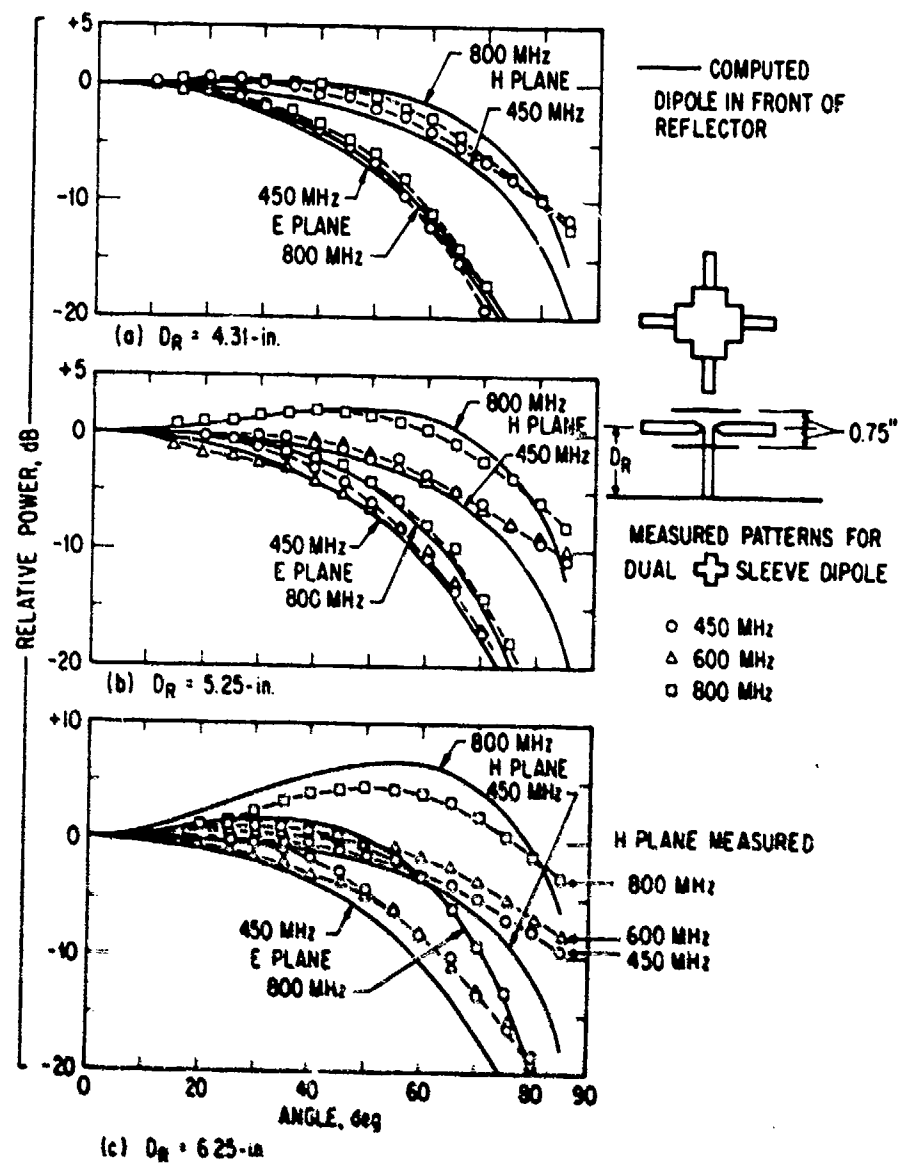


Fig. 21. Theoretical and measured patterns

V. GAIN

The gain of a crossed dipole with a tick-tack-toe sleeve configuration mounted in front of a 42-in.-diam reflector was measured for dipole-to-reflector spacings of 3.31, 4.31, 5.31, and 6.31 in. A detailed description of this dipole-sleeve arrangement can be found in Ref. 1. For each dipole-to-reflector spacing, the gain was measured at five test frequencies: 450, 500, 600, 700, and 800 MHz. The dipole and sleeve dimensions were fixed for all these measurements (see Fig. 22). Linear polarization was used, and a calibrated corner reflector was used as the reference gain standard at each test frequency. The gain was measured at the balun input port of each of the orthogonal dipoles, with both a horizontally or vertically polarized transmitter, and the measurements were performed at various range distances outdoors as well as inside an anechoic chamber. A large number of data points were recorded as shown in Fig. 22. The measured gain values were corrected for the mismatch losses; i.e., the antenna was assumed to be matched to $50\ \Omega$ at the input. The gain of a thin $\lambda/2$ dipole in front of an infinite reflector is also shown for comparison (Ref. 4).

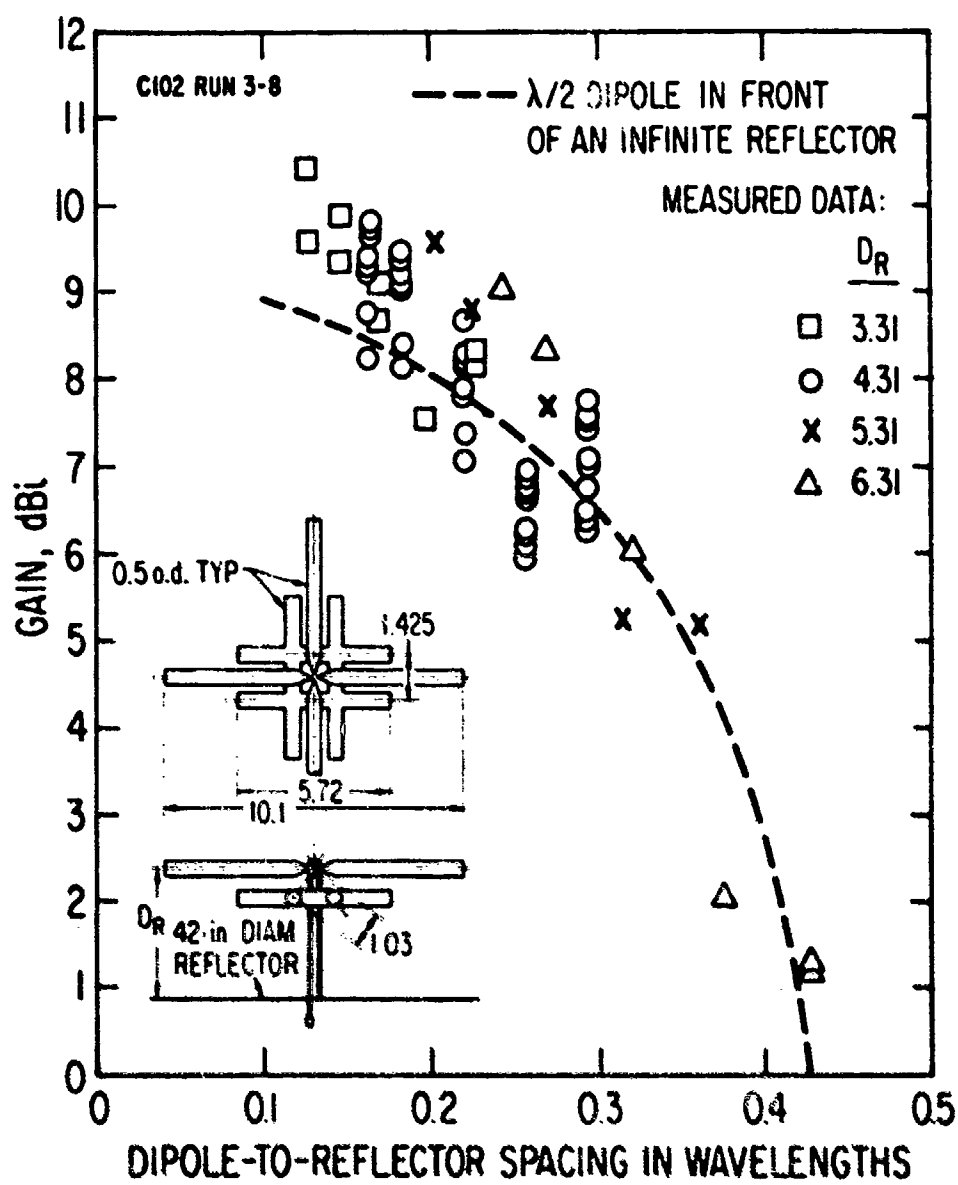


Fig. 22. Measured gain of dipole with a tick-tack-toe sleeve

VI. SUMMARY AND CONCLUSIONS

A detailed study has been made of the VSWR, pattern, and gain characteristics of the open-sleeve dipole. Experiments were performed with various sleeve configurations. Sufficient information is provided for one to select a sleeve antenna with wide VSWR bandwidth and with the knowledge of its patterns. There is a multitude of parameters that can be varied to derive the desired VSWR and pattern characteristics for a given application. Variations of the sleeve shape, sleeve-to-dipole spacing, and number of sleeves affect the bandwidth and the midband peak VSWR. Generally, the midband VSWR can be improved as the operating bandwidth is decreased. The low-frequency VSWR response is determined primarily by the dipole length and is not affected by the sleeve parameters.

Comparison of the measured patterns with the theoretical patterns of a thin-dipole in front of an infinite reflector revealed some interesting features. For relatively small sleeve-to-dipole spacings, the measured patterns conform fairly well to the computed patterns. However, the measured patterns show less variations over a 1.8:1 frequency band when the dipole-to-reflector spacing is fixed. Gain measurements on a tick-tack-toe sleeve dipole mounted on a 42-in.-diam reflector reveal that the gain versus dipole-to-reflector spacing in terms of wavelength has the same general trend as that of a theoretical $\lambda/2$ dipole in front of a reflector.

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